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ASSESSING THE IMPACT OF INFORMATION TECHNOLOGY ON COMMAND AND CONTROL: MEASURES OF MERIT

by

Valdur Pille

September / septembre 1999

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Section Head / Chef de Section

8 oct 99

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ABSTRACT

This document presents approaches for assessing the impact of Information Technology on Command and Control. The determination of the contribution of Command, Control, Communications and Intelligence (C3I) systems on military mission effectiveness has proven to be a complex problem, particularly with the depth and breadth of military organizations, and the wide range of their operations. The evaluation of C3I systems necessitates the application of a framework and a methodology to yield appropriate Measures of Merit. No single measure or methodology exists that satisfactorily assesses the overall effectiveness of command and control systems. Therefore a multi-method, multi-phase approach is necessary. Hierarchies of measures are defined, example frameworks and structures for assessments are presented, and factors relevant to and affecting these assessments are discussed.

RÉSUMÉ

Ce document décrit des méthodes pour évaluer l`impact de la technologie de l`information sur le commandement et contrôle. L`évaluation de la contribution des systèmes de commandement, contrôle, communications et renseignements (C3R) à l`efficacité des missions militaires est une question complexe. Cette complexité augment avec l`ampeur et la profondeur des organisations militaires, ainsi que la diversité des opérations auxquelles elles sont participent. L`évaluation de C3R nécessite l`application d`un cadre de travail et d`une méthodologie permettant l`accès aux mesures d`efficacité appropriées. Aucune approche ni méthodologie ne permet à l'heure actuelle d`évaluer de façon appropriée l`efficacité globale des systèmes de commandement et contrôle. Par conséquent, une approche par phases impliquant plusieurs méthodes est nécessaire. Un ensemble de mesures hiérarchiques est défini, des exemples de cadres de travail et de structures d`évaluation sont présentés et les facteurs pertinents qui pouraient affecter ces évaluations sont discutés.

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EXECUTIVE SUMMARY

The determination of the impact of Command, Control, Communications and Intelligence (C3I) systems on military mission effectiveness has proven to be a complex problem, particularly with the depth and breadth of military organizations, and the wide range of military operations. The key considerations of any assessment are the establishment of the objectives in the evaluation, the definition of what is meant by beneficial, in what manner, and by whom. The benefits should be evaluated by the impact on the fulfilment of the military objectives within the scope of potential missions. The impact should be measured in terms of defined qualities that are relevant to the objectives, and must span the hierarchies of the military organization.

The benefits of the application of information technologies (IT) on C3I must be determined in a reliable and systematic manner. The benefits attributed to information systems may be statistically difficult to prove with the multitude of uncontrollable variables and unmeasurable attributes. From a system's perspective, the classical approach is to compare the output of the system with its input. Measures of productivity are defined in terms of the ratio of output to input, which are multidimensional and problematic to identify. In this context, the system encompasses the total military environment, with IT contributing to the processes within the system. The incremental contribution of IT would be reflected by an incremental improvement in productivity and therefore effectiveness.

A four level hierarchy of measures has been proposed by the US Military Operational Research Society. They encompass: a) Measures of Force Effectiveness (MOFE) for measures of mission effectiveness; b) Measures of Effectiveness (MOE) for measures of functional organizational performance external to C3I systems ; c) Measures of Performance (MOP) for measures of attributes of internal system behaviour; and d) Dimensional Parameters (DP) for measures of characteristics inherent in physical entities.

No single measure or methodology exists that satisfactorily assesses the overall effectiveness

of C3I systems; therefore a multi-method, multi-phase approach is necessary. The evaluation of C3I systems necessitates the application of a framework and a methodology to yield appropriate Measures of Merit (MOM). Analyses of C3I systems reveal a complex hierarchical composition. A structured resolution/functional decomposition approach can be related to the organizational structure to yield performance measures for the organization as a whole, for individual components within the organization, and for specific tasks within the cells. An evaluation framework encompasses several factors: a) the evaluation configuration; b) the evaluation goal or purpose, c) the context, assumptions, and constraints, d) the evaluation domain, e) the identification of specific measures, f) the specification of the measures, g) the scenario or stimulus, and h) the collection means.

Other factors relevant for evaluation include the role of Command and Control models, scenarios, and the effects of uncertainty.

LIST OF ACRONYMS

ACCES	Army Command and Control Evaluation System
AFCCIS	Air Force Command and Control Information System
AHWG	Ad Hoc Working Group
C2	Command and Control
C3I	Command, Control, Communications and Intelligence
C3R	Commandement, Controle, Communications et Renseignements
CCIS	Command and Control Information Sytsem
CILR	Commander's Information List Requirements
COBP	Code of Best Practice
CPX	Command Post Exercise
DP	Dimensional Parameters
IO	Information Operations
IT	Information Technology
LFCS	Land Forces Command System
MAUT	Multi-Attribute Utility Theory
MCES	Modular Command and Control Evaluation Structure
MCOIN	Maritime Command Operational Information Network
MOE	Measure Of Effectiveness
MOFE	Measure Of Force Effectiveness
MOM	Measure Of Merit
MOP	Measure Of Performance
MORS	Military Operational Research Society
OOTW	Operations Other Than War
OR	Operations Research
NATO	North Atlantic Treaty Organization
R&D	Research and Development
RSG	Research Study Group

TRAC	TRADOC Analysis Command
US	United States

1.0 INTRODUCTION

Throughout history, the application of state-of-the-art technologies has been a force multiplier for military effectiveness. The Gulf War graphically portrayed the impact of technology on weapon effectiveness, where targets were destroyed with unprecedented precision. However, it is less evident how technology contributes to the broader scope of Command and Control (C2).

The determination of the impact of Command, Control, Communications and Intelligence (C3I)[1] systems on military mission effectiveness has proven to be a complex problem, particularly with the depth and breadth of military organizations and the wide range of military operations. Improved C3I system performance does not necessarily imply enhanced effectiveness of military operations. It is often difficult to show convincingly that investments in modern information technology for command and control may be more beneficial than investments in other areas. The Navy is currently upgrading their C3I system (MCOIN), the Army is procuring a system (LFCS), the Air Force is in the process of defining a system (AFCCIS), and a high level joint system is also in the definition stage. Occasionally, decisions to invest in systems are made without necessarily following a rigorous analysis of the potential benefits. The Auditor General's report of 1994 [Ref. 1] stated that the Information Technology (IT)[2] systems should be subject to a full cost-benefit analysis with quantified performance factors.

The key considerations of any assessment are the establishment of the evaluation objectives, the definition of what is meant by beneficial, in what manner, and by whom. The benefits should be evaluated by the impact on the fulfilment of the military objectives within the scope of potential missions. The impact should be measured in terms of defined qualities that are relevant to the

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[1] The nuances between the definitions of C3I and Command and Control (C2) are not discussed in this document and may be used interchangeably.

[2] The application of Information Technology implies Command and Control Information Systems.

objectives, and must span the hierarchies of military organization.

During the last two decades many new automated command and control systems have been developed and fielded. However, progress in the determination of the effectiveness of these systems has been limited. The US Military Operations Research Society (MORS) has sponsored several workshops on Measures of Merit (MOM) since 1985. These workshops have led to the development of an analysis framework (MCES - Modular Command and Control Evaluation Structure) for the measurement of performance and effectiveness within a conceptual model for Command and Control [Ref. 5, 23]. The US TRADOC Analysis Center (TRAC) developed the C2 Measures of Effectiveness Handbook [Ref. 2] in 1990 based on the MORS workshops.

The NATO AC/243 Panel 7 Ad Hoc Working Group (AHWG) on the Impact of C3I on the Battlefield [Ref. 20] acknowledged that the specification of measures of effectiveness is difficult. The 1992 final report recommended that a hierarchy of measures be established as an important step in understanding overall system effectiveness, and that systems be analyzed at different levels of detail. The types of measures were grouped relating to C3I system's performance, force/commander effectiveness, and battle outcome. To quote from the final report, "Measures . . . are often inadequate and too model or scenario specific. In addition, they have often been generated in ad hoc ways, suggesting a lack of formal analysis in their development."

In 1995, NATO Research Study Group 19 was formed with the aim of identifying methodologies for doing C3I evaluations in order to provide information on how to represent C3I effects on military operations. The product of the RSG-19 was a Code of Best Practice (COBP) for the determination of effectiveness of C3I, with emphasis on models, Command and Control organizations, scenarios, and measures of evaluation [Ref. 21]. This document reflects in part the author's contribution to the COBP, i.e. the Measures of Merit section for which he was responsible; members of RSG-19 also provided valuable suggestions on measures of merit for C3I.

2.0 MEASURES OF MERIT

2.1 Background

The benefits of the application of information technologies for C3I must be determined in a reliable and systematic manner. With hundreds or even thousands of variables and attributes involved in complex Command and Control systems, and with boundary conditions that are often not specified, this goal is a particularly challenging one. The benefits attributed to information systems may be statistically difficult to prove with the multitude of uncontrollable variables and unmeasurable attributes. From a system's perspective, the classical approach is to compare the output of a system with its input. Measures of productivity are defined in terms of the ratio of output to input, which are multidimensional and problematic to identify. In this context, the system encompasses the total military environment, with IT contributing to the processes within the system. The incremental contribution of IT would be reflected by an incremental improvement in productivity and therefore effectiveness.

Information systems are expensive to procure, deploy and maintain; the *value* of these systems is expected to overcome the costs. The task remains of quantifying the term value, and of identifying linkages to the effectiveness of the organization. To enable this identification, the effectiveness of information systems requires the a priori identification of the purpose of the system. By adopting a process-oriented view of the organization, measurements may be identified from the impact of information technology on intermediate organizational processes. Benefits such as cost reduction and increased productivity may be discernable. Nevertheless, the benefits of IT may be intangible (for example, increased flexibility) and are therefore difficult to identify, quantify and measure. IT may also provide value-added attributes of increased precision and decreased response times, i.e., more accurate information with quicker response times would provide better decisions within limited windows of opportunity.

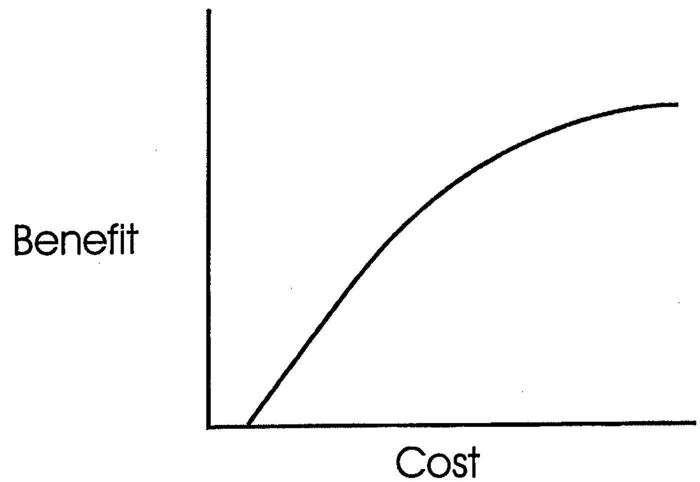

FIGURE 1 - Cost / Benefit Curve

In a business environment, financial indicators such as Return On Investment, Return On Equity, Return On Assets, etc. are often used as outputs. One may expect a relationship such as depicted in Fig. 1, with continuing improvement in return for increasing investment. However, the relationship to an input, such as investment in technological assets, to these indicators is not obvious. Some researchers, such as Strassmann [Ref. 22], raise the spectre of the *productivity paradox* with the claim that there is no relationship between investments in information technology and productivity (see Fig. 2, which plots investments from different companies). This apparent paradox is controversial, since the data plots the results of the performance of different unrelated companies to the performance indicators. A more appropriate approach is to measure the incremental improvement in productivity with incremental investments in technology within the same organization.

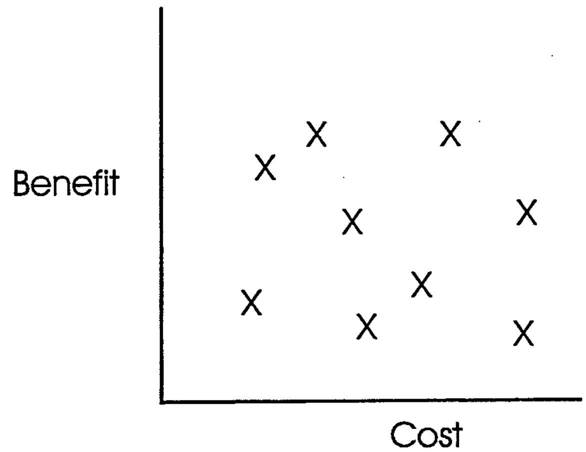

FIGURE 2 - Cost / Benefit Samples

Financial indicators of the business community may not be applicable in the military environment, and an added perspective on measures of the benefits of information technology at the high level is required. From the system's perspective, the military "output" may be defined in terms of peacetime readiness or force effectiveness. The determination of the impact of IT in turn requires the functional decomposition through the organization's hierarchies to identify military processes affected by IT.

2.2 Purposes of Obtaining Evaluation Measures

An important step in the design of an evaluation is the establishment of the objectives of the evaluation. With clear objectives, the formulation and identification of the measurements is greatly facilitated. Measures of Merit (MOM) have different purposes across a wide scope, with specific intentions, as outlined below:

a. for new requirements, the establishment of standards or expectations of performance;

the establishment of the bounds of performance of a system and the effects of imposed

constraints;

b. the comparison and selection of alternative systems that may be very different but are designed to achieve a similar purpose;

c. the assessment of the utilization of a system in new or unexpected application domains or missions;

d. the identification of potential weaknesses in specific areas of an organization or system (areas of high error potential or high user workload);

e. the analysis of the impact of organisational change;

f. the determination of the effectiveness of training;

g. the determination of the most cost-effective approaches to achieve desired objectives;

h. the comparison of a replacement system, or components of the system, against its predecessor;

i. assistance in requirements generation and validation, and the derivation of specific Command and Control requirements from broad statements of objectives;

j. the evaluation of the effectiveness and performance of human decision making in the Command and Control cycle.

The clear statement of the objectives of an evaluation allows one to focus on the definition of measures, and to plan the means of obtaining values for these measures.

2.3 Definitions of Measures

The important issues raised by decision makers are how to arrive at judgments on the degree that Command and Control acquisitions may improve force effectiveness, and subsequently provide convincing demonstrations of the improvements. An approach may be to define a single measure that objectively reflects the military and political objectives of the missions under consideration. However, such a measure may not be practically obtainable, and furthermore, a single measure would not provide a means of analyzing the impact of specific command and control elements on force effectiveness.

To understand the impact of C3I, it is not only necessary to analyze and measure the effect of the C3I on military operations, but also of the components of the constituent systems. Therefore, classes of measures are required, with appropriate definitions. The terms "effectiveness" and "performance" may be viewed as the same concept, but viewed from different perspectives, i.e. "performance" may be viewed in terms of "effectiveness" at a higher level. These expressions are often used interchangeably, with ambiguous reference to what are the objects of measure. The term *Measures of Merit* is recommended as a generic terminology to encompass different measures. The measures are best defined in hierarchical levels related to each other, each concerning its own boundary. From the conceptual viewpoint, the level of analysis and the context in which the measurements are made are important.

Within the MCES framework, MORS has developed a four-level hierarchy of measures from the high level of force effectiveness to the low level of rudimentary measures of physical entities. These are:

a. Measures of Force Effectiveness (MOFE): Measures of how a military force achieves its mission or the degree it meets its objectives. Examples are loss exchange ratios, number of targets destroyed.

b Measures of Effectiveness (MOE): Measures that are external to C3I systems of functional organizational performance within the operational context. Examples are number of targets detected, time to perform specific tasks.

c. Measures of Performance (MOP): Measures of attributes of internal system behaviour. Examples are information retrieval times, message transmission times.

d. Dimensional Parameters (DP). Properties or characteristics inherent in the physical entities, e.g. signal to noise ratios, bandwidth.

This hierarchical definition allows the linking of lower level measures to higher levels. The lower level measures may be analyzed to provide an indication of the impact on higher level measures. However, the linkages may be difficult to establish, the assumptions and constraints must be clearly stated and critical paths at the same level must be identified. The effectiveness of C3I systems must be evaluated in terms of their influence on military effectiveness, with the appropriate determination of the linkages and causal relationships of the measures of merit.

The relationships between MOM, the environment, forces, C2 systems and their components are presented in a simplified form in Fig. 3. For a particular analysis, it is important to identify the specific boundaries, whereupon the measures are then bound to the specific context.

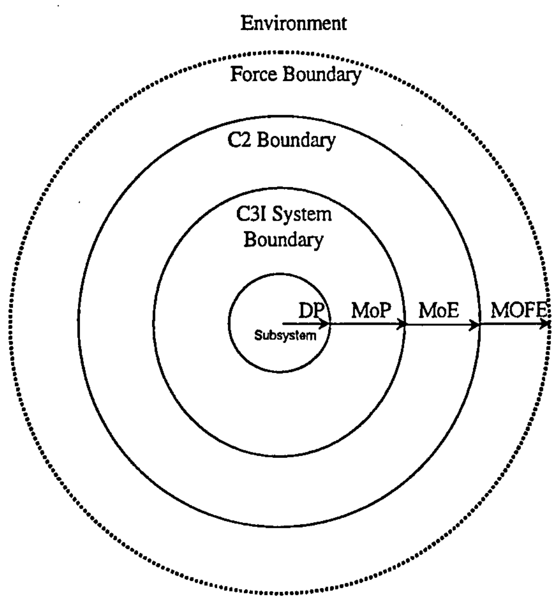

FIGURE 3 - MORS Relationships of Measures of Merit

2.4 Characteristics of Measures

The relationship between these types of measures is often difficult to establish authoritatively. Linkages between lower level measures (DP and MOP) are easier to determine than those to the higher level measures (MOE and MOFE), particularly when small numbers of observations are available, so that correlation techniques are not appropriate and/or controls are not available to isolate causal effects. Higher level measures tend to be more subjective while lower level measures tend to be more quantitative. MOE and MOFE are more dependent on the operational context and therefore more scenario dependent. This implies the necessity for a selected range of scenarios for the proper analysis and interpretation of the measures. MOFE tend to be few in number and expensive to obtain. By themselves MOFE do not reveal much about the underlaying C3I system, and therefore should be used in context with MOE and MOP that provide "diagnostic" information about the dynamics of the C3I process. The two central levels (MOE and MOP) yield the most insight into command and

control systems. DP should be collected when they can be obtained cost effectively in order to check for physical characteristics of the C3I system components that may be creating problems at the MOP level. Table I lists general characteristics of the types of measures.

TABLE I

Tendencies of Characteristics of MOM

MOM	Scenario	Cost/ Effort	Number	Value	Compre- hension	Subj/ Obj	Type
MOFE	Depen- dent	High	Few	Less (alone)	Military	Sub- jective	outcome
MOE							
MOP							
DP	Indepen- dent	Low	Many	More	Techni- cal	Ob- jective	process

2.5 Properties

This section outlines measurement theory concepts that apply to ensure that the right measuring instruments are selected and applied correctly. By definition, measurement is the assignment of values to observation units expressing properties of the units. Three levels of measures relate numbers to properties of interest: ordering in rank (e.g., small to large), equal intervals (e.g., 50% increase in baud rate), and ratios or absolute values (e.g., 56 kilobaud). A fourth level may be defined as nominal assignment, i.e., using numbers as labels, but is not relevant to MOM. Ratio level measurement possesses an absolute zero value, and has the properties of interval level measurements.

In turn, interval level measures possess both quantity and ordering.

The key properties for quality assurance in evaluation methodology are reliability and validity. A third property is cost and convenience; the measurement should be cost-effective and easy to apply. This property bears no direct relationship with validity, but reliability is directly related to cost. Reliable measurements require repeated measurements to obtain large sample sizes. A cost-effective measurement plan provides just enough data for useful and definitive conclusions. However, cost may be an overriding factor in system evaluation.

Failure to take into account the principles of validity and reliability raises the risk of generating false conclusions. Validity and reliability are not absolutes, but matters of degree. Validity is the degree to which the measure focuses on the attribute of interest and only on that attribute. Reliability represents precision and repeatability. A measure may be reliable but not valid, or it may be valid but not reliable. In order to link the performance of a system as a whole against that of its components, the measures must correspond to critical tasks to be valid.

MCES lists several quality criteria for measures, which may be grouped according to the properties related to reliability and validity according to the following tables.

TABLE II

MCES Reliability Criteria of Measures

Reliability Criteria	Definition
Discriminatory	Can identify real differences between alternatives
Measurable	Can be computed or estimated
Quantitative	Can be assigned numbers or ranks
Objective	Can be defined or derived, independent of subjective opinion
Sensitive	Can reflect changes in system variables

TABLE III

MCES Validity Criteria of Measures

Validity Criteria	Definition
Mission Oriented	Relate to force/system mission
Realistic	Relate realistically to the C2 system and associated uncertainties
Appropriate	Relate to acceptable standards and analysis objectives
Inclusive	Reflect those standards required by the analysis objectives
Simple	Easily understood by users

2.5.1 Validity

The property of validity may be categorized into four types: internal, construct, statistical and external.

Internal validity is defined as the establishment of causal relationships between variables of interest. This is necessary to validate the hypothesis that a given measure is responsible for a specific

effect on another measure.

Construct (also referred to as content) validity means that the target object, and only the object, is measured.

Statistical validity implies that sufficient sensitivity is involved in order to determine relationships between independent and dependent variables. Statistical tests control two types of errors in measurement. Type I or alpha is the probability of rejecting a claimed hypothesis while it is true (e.g., concluding that a new automated decision aid does not reduce the time to prepare a plan, while it in fact does). Type II or beta is the probability of accepting a hypothesis while it is not true (e.g., concluding that a new decision aid does reduce planning times, when in fact it does not).

External validity is the extent to which results may be extended to other populations or environments. Associated with this is expert validity, which refers to the degree to which measures are accepted by those who are knowledgeable in the field.

2.5.2 Reliability

Reliability involves the expectation of errors associated with measurements. It is defined as the amount of measurement precision, as measured by the variance of repeated measurements of the same object. The key principles of reliability are consistency (repeatability) and precision. The amount of error associated with measurements must be known to interpret the results and to discriminate between the real effects and error effects. Reliability assures that variance in a measure between systems is due to system differences and not errors in measurements. Reliability cannot be calculated, but only estimated. The correlation between two observations of the same measure is an estimate of the reliability. Theoretically, the validity correlation cannot exceed the square root of the estimated reliability of the measure. The variance in measurements may be due to random errors and/or systematic errors. Systematic errors may be reduced by applying different measurement approaches, and random ones by repetitive measurements.

2.6 Types of Measures

A common thread in the approaches for evaluation is the functional decomposition of the C3I cycle. Command and control effectiveness therefore depends upon the functional processes of the command and control system, and the evaluation of functions may be determined by data measured at the task level.

The evaluation of tasks provides the most detailed insight into C3I activities. The primary measures are in terms of time consumed and accuracy of actions. Task analysis must be performed prior to evaluation, with the identification of the task definition and of the critical elements for successful task completion.

Performance measures of a system's behaviour may thus be reduced to measures based on time, accuracy, or a combination of factors which may be interdependent. Time-based measures are quantitative, while accuracy measures may also be subjective.

2.6.1 Time

For command and control tasks, time-based metrics include:

1) Time taken to react to an event (time to notice new information, recognize/classify information, understand information);

2) Time to perform a task (time to make a decision);

3) Time into the future for predictive analysis; and

4) Rate of performing tasks (tempo).

2.6.2 Accuracy

Metrics for accuracy include:

a. precision of performance;

b. reliability of performance;

c. completeness (known unknowns, unknown unknowns);

d. errors (alpha, beta, omission, commission, transposition, severity); and

e. quality of decisions.

Some accuracy measures may be assessed in units of time; for example, the time taken to detect an error. The quality of decisions is difficult to evaluate objectively, except by focussing on outcomes. The processes involved may have to be examined to obtain objective measures, and subject matter experts may be called upon to make an evaluation. Accuracy of information implies both the accuracy of the data and the accuracy of the interpretation of the data.

2.6.3 Relationships - time and accuracy

Time based and accuracy based measures often bear an inverse relationship, implying a tradeoff between speed of performance and accuracy of performance. Speed of performance must be specified in terms of minimum desired accuracy or completeness, and accuracy measurements in terms of time available. Therefore, the specification of thresholds or standards for metrics must be referenced in terms of imposed constraints.

2.7 Examples of Hierarchical Measures

This section outlines examples of Measures of Merit. Since, as previously stated, MOE and MOP provide the most insight into C2, emphasis is put on these hierarchical levels.

2.7.1 Measures of Force Effectiveness - MOFE

MOFE are high level measures that are few in number with more military than technical meaning. Examples of such measures include:

a. territory gained / lost;

b. mission objectives achieved;

c. battle won / lost;

d. ratio of enemy losses to friendly losses;

e. number of targets destroyed; and

f. percent Combat Effectiveness.

2.7.2 Measures of Effectiveness - MOE

Table IV contains examples of time- and accuracy-based measures. These measures are of the MOE level. The measures may be expressed in quantative units of time, percentage, or absolute values, or of subjective interpretation.

TABLE IV

MOE Time and Accuracy Measures

Measure	Example
Time	**Based**
Time taken to perform a fixed task or sequence of tasks	Planning tasks
Time to perform a variable task	Developing and selecting options or courses of action
Time to recognize or respond to an event	Response to a critical enemy contact
Time to achieve a target state	Tactical objective
Percentage of time on target	Enemy location data up to date
Intelligence latency	Time taken to reflect ground truth
Number of events in queue	Messages pending action
Timeliness of response	Fire plan schedule
Accuracy	**Based**
Accuracy or precision of performance of tasks	Information on maps, data bases
Sensitivity of detecting system events	Recognition of events requiring change in plans
Probability of making errors	Errors in fire plan target schedules
Time to recognize existence of error	Necessity for plan alteration
Time to recover from error	Time to redo part of plan
Knowledge of current system status	Comprehension of battle situation
Quality of decision making	Quality of tactical plan

2.7.3 Measures of Performance - MOP

A bottom-up approach [Ref. 16] to the establishment of measures provides three types: technical services attributes, user effectiveness attributes, and ineffectiveness attributes. These are outlined in the following table, and yield measures mainly at the MOP level.

TABLE V

MOP Measures

Technical Services Attributes - Hardware and Software	
Availability	Functional capabilities available to users
Survivability	Ability to survive partial destruction of system
Robustness/Endurance	Ability to adapt to environment
Maintainability	Ease of repair or replacement during operation
Computation Capacity	Acceptable response times to users
Portability	Ability to operate on different platforms
Mobility	Ability to move with operational units

Technical Services - Applications Attributes	
Interoperability	Communications with other C3I systems
Security	Confidentiality and integrity of data
Confidentiality	Information protected at appropriate level
Integrity	Required for confidence of data
Customizability	Ability to customize parameters to actual activities
Quantity of Information	Provide all information required by user
Bandwidth	Ability to support multi-media

User Effectiveness - Information Quality	
Selectivity	Ability to provide required information at required amount
Accuracy	Degree information provided is correct
Comprehension	Facilitate understanding of situation

User Effectiveness - Time Related	
Response time	Response to requests within established times
Timeliness	Information available at appropriate time
Ease of use	Ease of access to information in a timely manner
Training time	Time to train users
Decision response time	Time available to commanders

User Effectiveness - New Capability Related Attributes	
Uncertainty Management	Ability to take into account ambiguity and uncertainty
Simulation	Ability to realistically test courses of action before decision
Information Age Management	Ability to store information for later analyses

User Effectiveness - Motivation	
Communication Acknowledgment	Positive feedback
Knowledge of Consequences	Positive for stimulus but negative for stress
Confidence of Information	Not used if untrustworthy
User friendliness	Adaptability to different users
Participation in Development	User buy-in

Ineffectiveness Attributes	
Loneliness	Isolation from real world
Interference	Micro management
Wait and see	Waiting for confirmation instead of deciding
Wargame	C3I reflects real situations

2.7.4 Dimensional Parameters

At this level, the focus is on subsystem parameters which are usually static and provide information on the capabilities of equipment. Examples are;

a. Signal-to-noise ratios
b. Bandwidth
c. Resolution
d. Floating point operations per second
e. Radar cross-section
f. Radar resolution
g. Bit error rate.

2.8 Summary of Measures

It has been stated that MOE and MOP provide the most insight to C2. These measures described in the above sections, among others, are summarized in Table VI.

Table VI

Summary of Measures

Measure	*Definition*
Time	Elapsed duration
Accuracy	Degree of correctness
Completeness	Extent known of whole or desired objective attained
Cost	Savings in operations, maintenance
Adaptability	Anticipation of contingencies
Flexibility	Ability to respond to foreseen possibilities
Robustness	Ability to withstand unforeseen situations
Sustainability	Ability to maintain tempo
Survivability	Ability to withstand degradation
Security/Vulnerability	Information Operations
Reliability/Availability	Extent system performs as expected
Efficiency	Reduced manpower and resource requirements
Readiness/Responsiveness	Delays in achieving desired state
Navigation	Mechanisms to obtain information, data structures
Coherence	Logical and consistent relationships
Consistency	Same results with same conditions and actions
Sensitivity	Degree variations in input required to effect outcomes
Integrity	Soundness of operations
Relevance	Appropriate reference
Risk reduction	Reduced possibility of negative outcomes
Confidence	Reduced uncertainty

2.9 Headquarters C&C Performance Measures

Performance measures may be divided to sets corresponding to the C2 cycle:

a. Monitor: information transmission, values, times, effect, comprehension;
b. Plan: information exchange, impact, alteration, quality; and
c. Direct and disseminate.

The measures are related to three levels: the headquarters as a whole, the individual cells within the headquarters, and the performance of specific tasks within the cells.

Appendix A outlines an approach for land forces Division HQ evaluations for planning and monitoring [Ref. 11].

3.0 EVALUATION FRAMEWORK

The evaluation of C3I systems necessitates the application of a framework and methodology to yield appropriate Measures of Merit. Analyses of C3I systems reveal a complex hierarchical composition. A structured resolution/functional decomposition approach can be related to the organizational structure to yield performance measures for the organization as a whole, individual components within the organization, and specific tasks within the cells.

Assuming that Command and Control effectiveness is synonymous with overall unit effectiveness, MOM could be obtained by addressing the outcomes or products of unit activities. Goal level evaluation attempts to define the ability of the specific formation to make the environmental state match the goal (directive) provided by the superior headquarters. The degree that the environmental state matches the desired goal states indicates a level of effectiveness. Alternatively, Command and Control effectiveness may be viewed as dependent on the functional processes of the command and control system, with measures obtained mainly at the task level.

An evaluation framework encompasses several factors:

a. the evaluation configuration (e.g., storyboard, testbed, full-scale simulation, field trial);

b. the evaluation goal or purpose;

c. the context, assumptions, and constraints;

d. the evaluation domain, i.e., MOFE, MOE, MOP, DP;

e. the identification of specific measures;

f. the specification of the measures;

g. the scenario or stimulus;

h. the collection means, e.g., subject matter experts, automatic logging; and

i. the interpretation of the results;

3.1 Modular Command And Control Evaluation Structure (MCES)

MCES prescribes a process of measurement, but does not identify either a measurement system or a set of measures. Similarly, while calling for the collection of data, MCES does not provide details on how data are to be collected. MCES does provide guidance on how good measures and good collection procedures are characterized, but leaves the details of the measurement, data collection, and analysis plans to the analyst.

Evaluation of C3I effectiveness requires a comprehensive approach for the preparation of the evaluation process, the collection of data, and its interpretation. MCES addresses both the managerial and analytical aspects of evaluation, and was originally developed for the systematic comparison of C2systems. The objective of MCES is to guide analysts in the identification of appropriate measures for estimating the effect of C2 on combat.

MCES considers C2 as consisting of three components: physical entities (equipment, software, people), structure (interrelationships between entities) and processes (C2 functions). The boundary of a C2 system is defined as a delineation between the system studied and the environment. The TRADOC C2MOE Handbook adds mission objective as the top layer of the hierarchy of C2 components.

MCES focuses on measures as opposed to models, but includes the cybernetic loop (Lawson) model of generic C3. It consists of seven procedural steps as shown in Table VII

Table VII

MCES Steps

Step	Procedure	Product
1	Formulate the problem	Problem Statement & Scenario
2	Bound C2 system	System Elements
3	Define C2 process	System Functions
4	Integrate elements and functions	System Architecture
5	Specify measures at boundaries	Functional Measures
6	Generate data for measures	Values
7	Aggregate and integrate results.	Analysis of Results

3.1.1 Problem Formulation

This step provides a description of the analysis objectives from the viewpoint of the C2 system life cycle, and the level of analysis prescribed. Assumptions are stated, and the scenarios selected.

3.1.2 C2 System Bounding

The system elements are identified and categorized. The C2 system of interest is bound in terms of physical entities (equipment, software, staff), structure (organization, concepts of operation), and C2 processes. The boundaries are identified in terms of subsystems, C2 systems, own forces,

and the environment.

3.1.3 C2 Process Definition

The functions of the C2 process are identified and mapped to the generic C2 cycle (sense, assess, generate, select, plan, direct), and the inputs and outputs to the processes are identified. Insight to C2 is obtained by decomposing the C2 cycle into functions/subfunctions, processes, and tasks. These are situation independent descriptions of responsibilities of the elements constituting the military organization. The Monitor, Assess, Plan, and Direct high level functions are further decomposed into sub-functions. The term processes in this context defines the interrelationships of tasks performed to fulfill the functions.

3.1.4 Integration of Elements and Functions

This step defines the relationships between the C2 processes, physical entities, and structure. Input/output relations are derived to describe the internal information flows between separate process functions, and physical entities that perform functions are mapped to the outputs. The hierarchical relationships between C2 functions are determined, and an organizational structure is produced.

3.1.5 Specification of Measures

This step results in the specification of measures focussed primarily on the C2 process functions. The measures are classified according to the four levels previously defined. The MCES defines the following attributes for MOM:

a. name and category;
b. system reference (boundary);
c. function reference (purpose);
d. units of measure;

e. value measured; and

f. threshold value.

3.1.6 Data Generation

The generation of values for the identified measures may be performed by various means such as exercises, experiments, simulations, and subjective judgments. The values may be measured directly or be derived from other measures. For the evaluation of new systems, the generation may be assisted by designing into the system functions to yield specific measurements.

3.1.7 Aggregation of Measures

For the aggregation and analysis, particular attention must be paid on the causality, sufficiency, and independence of measures. Some measures (e.g., time intervals in the C2 cycle) may be directly aggregated, although the critical paths must be identified for meaningful results.

4.0 EXAMPLE METHODOLOGIES

4.1 Army Command and Control Evaluation System (ACCES)

ACCES [Ref. 4, 12-15] is a derivation of HEAT (Headquarters Effectiveness Assessment Tool) [Ref. 3, 6-10], which was developed primarily for joint theatre level operations. ACCES reorganized HEAT concepts into army doctrinal language and doctrine, but shares the same philosophy. ACCES has been applied to numerous Division and Corps command centre assessments. It represents a comprehensive set of practical and objective performance measurements for C2 activities. The primary focus of ACCES is the overall performance of a command centre, or network of command centres, at various stages of the command and control process, from the collection of data to the conversion of data into intelligence, and to the implementation of plans and directives. The underlying approach to ACCES is that command and control comprises interdependent sub-process that can be observed and measured. ACCES considers C2 as an adaptive control process, where information collected from the outside is processed internally for generation of plans, which may be adapted to new information. ACCES takes the view that the overall effectiveness of a command centre can be judged by the viability of its plans. A good plan is one that can be executed without the need for modification beyond the contingencies stated in the plan, and remains in effect throughout its intended life. The ACCES measures are listed in Table VIII.

Table VIII

ACCES Measures

MONITOR	
Completeness	Commander's Information List Requirements (CILR) for which there are data.
Accuracy	Units or CILR items for which headquarters data are within the desired window of accuracy.
Querying	Units where most recent data are outside the desired time window.
Timeliness	Units for which the most recent data are within the desired time window.
Impact on plan	Control cycles initiated because of monitoring errors.
Forecast correctness	Predictions of time at which change in weather and terrain are correct.

ASSESS AND UNDERSTAND	
Completeness	Periodic briefings requiring an understanding of the situation to be expressed, at which the understanding is actually stated.
Quality	Perceptions of the situation held by the headquarters, scored as percentage correct, not incorrect, or incorrect.
Impact of plan	Control cycles caused because headquarters understanding did not match ground truth.
Time to understand	Time from the expression of understanding to the end of the period covered for the understanding.

GENERATE AND PREDICT	
Multiple options	Number of options considered.
Multiple planners	Staff members who participate in the development of alterative course of action.
Prediction completeness	Estimates that include, for each option presented, predictions of enemy reaction, degree of mission accomplishment, and residual capacity of friendly and enemy units involved.
Prediction quality	Predictions scored as "correct", "not incorrect" or "incorrect".
Prediction time	Time from the making of an estimate to the end of the time covered by the associated predictions.

DECIDE	
Plan quality	Plan assignments that remain in force unchanged for the intended period, expressed as a percentage of the total assignments. The assignments in a plan are: mission, assets, boundaries, and schedules.
Plan congruence	Control cycles arising from minor, moderate, or major incongruence.

PLAN	
Time from decision	Time taken to issue a directive after a decision has been made.
Plan consistency	Assignments in implementing directives which do not contradict a Commander's decision.
Plan clarity	Directives not queried by recipients.
Plan cycle time	Time used to complete the control cycle given minor, moderate, or major incongruence.

DIRECT	
Plan lead time adequacy	Directives for which planning lead time provided to subordinates is adequate.
Time induced aborts	Directives for which lead time is insufficient to allow a suitable response.
Query response time	Queries responded to within the specified time.

In addition to the above measures, ACCES includes two other sets of measures: (a) coordination measures, which are used to assess how well the staff gather information within their command centre and with counterparts in other command centres and (b) report measures used to assess how well the command maintains communications with superior, subordinate, and adjacent commands.

4.2 Multi-Attribute Utility Theory (MAUT)

Multi-Attribute Utility Theory or MAUT [Ref. 1], is similar to ACCES in the sense that both use functional decomposition and function specific evaluation metrics. The major difference is that MAUT assigns a utility component for each element and node in the hierarchy. MAUT then aggregates upwards the weighted scores to provide composite scores of effectiveness.

MAUT has been used by some practitioners to assess C3I in a particular context. MAUT is based on decision analysis and makes a variety of assumptions. The first is that the analyst knows all the factors that will influence performance. The second is that the analyst can properly weight those factors. Finally, MAUT assumes that the relationships between the independent and dependent

variables are known and properly specified. MAUT is therefore like MCES. It specifies a process for analysis, but leaves the task of identifying appropriate C3I theory and measures to the analyst.

The four key components of the MAUT framework are stimulus, hypothesis, option, and response, which could be mapped onto the C3I cycle. These functions are overlayed into an evaluation methodology of three aspects:

a. the interface between the system and user;

b. the relationship between the user and the organization; and

c. he interface between the organization and the environment.

Measures specific to each of the above aspects are identified, aided by the decomposition into a hierarchy of processes, functions, tasks and activities. For each element and node in the hierarchy, a utility component is assigned in perspective of the overall evaluation goal. The MAUT approach does not consider all tasks and functions assessed to be of equal value and importance. Finally, the weighted scores are aggregated upwards to provide composite scores for each nodal function and interface domain to obtain a measure of overall effectiveness.

Ultimately, MAUT analyses are only as good as the measurement and theory underlying them. For well understood, narrowly focussed problems, MAUT can be a powerful tool that both provides a sound structure for describing relationships and allows a variety of sensitivity analyses. However, in poorly structured problems or weak knowledge domains, MAUT is simply a way of looking at the consequences of different sets of assumptions

5.0 OTHER FACTORS FOR EVALUATION

5.1 C2 Models

A model is an abstraction representing the relationships among variable attributes of a system, and incorporates all variables of interest that may affect outcomes. Given the value of known attributes, the model provides predictive capabilities to estimate the values of other attributes with acceptable degrees of uncertainty. Whatever form a C2 model assumes (e.g., analytical, simulation), values should be produced for variables required to determine MOM with adequate detail and accuracy. Models are limited to the extent of the envelope of possibilities of military operations. For example few models exist for joint operations or echelon above corps and models may be limited in the scope of information warfare or other specific factors.

5.2 Scenarios

Relevant scenarios are required to stimulate each battlefield function, sub-functions, tasks, and organizational components within the context of the environmental aspects. Not all of these elements continuously interrelate and critical tasks must be identified. The scenario prescribes the tempo of operations and induces specific components of a C2 system to react. Partial evaluations may be merged by applying a range of (possibly overlapping) scenarios, with clearly defined hierarchies. Obviously scenarios and the models must reflect common hierarchies and levels of resolution.

5.3 Effects of Uncertainty

In order to state a level of confidence in the interpretation of MOM, the underlaying assumptions must be clearly stated and uncertainties be recognized. Uncertainties manifest themselves in several ways that may affect Measures of Merit, and may be grouped as follows:

a. Uncertainties in the scenario (model input): i.e., relevance to the purpose of the

evaluation, uncertainties in the military objective, knowledge of enemy concept of operations, intentions, capabilities, weapon performance, uncertainties in terrain data;

b. Uncertainties in the model (structural uncertainty): human performance, parameters, objects, attributes, processes, effects of constraints, effects of aggregation and disaggregation, deterministic (usually high level and low resolution) versus stochastic models (low hierarchical level and high resolution);

c. Uncertainties in the outcome: hypersensitivity to input variations, (instability or chaos theory where small variations in input could result in vastly different outcomes), effects of model non-linearities and non-monotonic behaviour (effects of thresholds), decision making for local versus global optimisations.

Sensitivity analysis may be applied to reduce uncertainty. By varying the assumptions and input data within ranges of uncertainty, excursions in the analysis will provide insight into the effects of uncertainty.

It should be noted that uncertainties in the scenario often reflect real-world situations where a range of diverse anticipated conditions may be encountered, or even unanticipated conditions occur. Measures under these conditions that may be considered are *flexibility* and *robustness*; flexibility for different anticipated situations, and robustness for the unanticipated.

5.4 MOM for Operations Other Than War

While national policies and NATO require that military forces be prepared for high intensity conflict, the forces have been increasingly involved in low intensity conflicts and Operations Other Than War (OOTW). OOTW include operations of force deployment to create or maintain conditions for a political solution for disputes before escalation into hostilities. Threats to international and national security may also unfold from natural disasters, organized crime, civil unrest, migration, other territorial intrusions. Most OOTW are characterized by their joint or combined nature.

While the determination of MOM has been stated as difficult to obtain, OOTW offers even more of a challenge, particularly at the MOFE level. Traditional MOE and MOFE such as percentage of time on target, loss exchange ratios, combat effectiveness, duration of the campaign are not always applicable to OOTW. In such operations, military forces may play important roles, but political concerns may limit the scope of imposition of solutions. Public and political pressures may result in shifts in the selection of criteria for MOM, e.g., more emphasis may be put on personnel casualties and less on equipment losses.

Mobility may be important for OOTW, as will as sustainability and self-sufficiency in theatre, with the implication of reliability and maintainability. Furthermore, the perception of the capabilities of deployed forces acts as a deterrence or coercion on each party in conflict.

Normality Indicators [Ref. 17] have been proposed as an indirect method for measuring the effects of military involvement in OOTW but causal relationships are difficult to prove. These measures may be obtained by evaluating the extent that conditions have been restored to previous levels.

Ref 18 developed low-level measures to cover OOTW. These include, for example:

a. time between arrival of friendly forces in the area and deployment of the forces;

b. time between deployment of friendly forces and contact with hostile forces;

c. length of time hostile forces were under observation without posing a threat to friendly forces; and

d. length of time friendly forces are in potential danger (i.e. hostile forces have opportunity to fire on friendly forces).

Ref 17 identified a structure that provides high-level measures for OOTW. These are:

a. opportunities to employ forces, which reflects the range of military capabilities available;

b. strategic deployment, related to deploying and recovering the right force to theatre efficiently and in time;

c. endurance, to maintain an effective force in theatre for an extended time;

d. mission objectives, to measure the success of achieving military objectives OOTW; and

e. successful termination, to deal with progress to the desired end state (the criteria may be political and not yield measures related to military activities).

5.5 Measures of Policy Effectiveness

For Operations Other Than War, political factors are paramount and considerations must be

taken into account such as media coverage, local regional stability, and sustainment of community societal standards. A new category of measures may be added to characterize the contribution of military actions to broader policy societal outcomes, Measures of Policy Effectiveness. While military missions may not directly achieve policy objectives, they may provide an environment more conducive to these objectives. However, measures of effectivenesss of military tasks should quantify performance against military missions, not the overall policy aspirations.

5.6 Information Operations

Information Operations (IO) may be considered as information dominance over opposing forces and its military application (from pre- to post-hostilities) in terms of Command and Control Warfare. The aims are to influence, degrade, or destroy adversary command and control capabilities and information links, while using countermeasures to protect own C2 assets. IO is a form of comprehensive warfare that may span peacetime, crisis, and combat governed by a strategy to obtain desired objectives that may be military, political, or economic. The ultimate objective is to affect the adversary's decision process, implying a hierarchical effect on opposing forces operations with, for example, attacks on sensors affecting information systems to the propagation of functional effects on decision making. For MOM, hierarchical levels similar to the MORS may be appropriate, but the MOM would be difficult to evaluate and become quite subjective at the higher levels.

6.0 CHALLENGES / ISSUES

Linkage of DP-MOP-MOE-MOFE: An improvement at one level does not necessarily imply an improvement at a higher level, e.g., increasing target detection MOE may result in an increase rate of fire and number of targets destroyed (MOFE), but only to the maximum sustainable rate of fire. Furthermore, the objective in an assessment may not be for improved MOFE, but for improvement at a lower level. IT may improve optimization of the utilization of assets with reduced resource requirements, without an intended effect on an MOFE. The correlation of measures with processes (e.g. battle outcome against lower level measures) requires considerable insight into the C2 environment. The accomplishment of the aggregation of measures requires the identification of critical paths at the same level, the discrimination of measures and the examination of the relationships between the measures. What are the effects of one measure on another, and how can we assure that only the desired measure is obtained?

Interpretation of measures: Measures may be quite judgmental due to imprecise system boundaries, imposed constraints, reference standards, and assumptions.

Environmental components: An evaluation requires the separation and linkage of CCIS and users / CCIS and organization / CCIS and military objective.

Summary measures: High level measures have limitations in diagnosis of command and control success or failure. How do a small number of summary measures provide a comprehensive assessment of the complexity of a command and control system?

Reliability and validity: Assessments are often approached with minimal attention to reliability and validity. The analyst must be prepared to demonstrate convincingly the veracity of the results of an evaluation.

Uncertainty: Measures may be affected by uncertainties in the scenario, the model and the outcome. C2 decisions are made in situations of degrees of uncertainty, therefore the outcome is of less significance in evaluation than in the evaluation of the quality of the process.

Human-in-the-loop: Variation in measurements due to human involvement may well cause unacceptable levels of uncertainty in the results of an evaluation.

Cost and convenience: Evaluations of the contributions of IT is labour intensive.. Measures may be obtained in conjunction with Command Post Exercises (CPX), but the formulation of CPX specifically for determination of measures is rarely done.

Training:. The effect of the "learning curve" on productivity in the use of new automated capabilities renders the object of the evaluation a moving target.

Modelling: Improvements in the modelling of C2 are required in fidelity and resolution across all hierarchical levels of interest. The impact of human-in-the-loop, especially in decision making, is difficult to model.

7.0 RECOMMENDATIONS

The principal objective for MOM is to determine judgements of the degree that C2 acquisitions may improve force effectiveness, and to provide convincing arguments for the improvements. It is important to stress that the purpose is to assess the contributions of C2 in terms of its effectiveness on military missions, and not on the quality of the C2 process itself. However, to arrive at these assessments, the C2 system must be included in the analysis. The following points are required in the assessments:

a. the objectives of the evaluation must be established and clearly stated;

b. assumptions used in the model must be stated as well as the constraints placed on either the evaluation process or the systems being assessed;

c. formal assessments of reliability and validity must be undertaken in order to place a level of confidence in the results of the measurement process;

d. concentrate effort on MOE and MOP, as they yield the best insight into C3I effectiveness (as opposed to DP and MOFE);

e. the capability to generate MOM should be included as part of system development; and

f. Subject Matter Experts should be included in studies of assessments.

8.0 CONCLUSIONS

No single measure or methodology exists that satisfactorily assesses the overall effectiveness of command and control systems; therefore a multi-method, multi-phase approach is necessary. As a minimum, the following factors must be considered in conducting an analysis of C2 systems:

a. determination of the hierarchy levels appropriate for the level of analysis to establish appropriate MOM;

b. identification of specific MOM that are practically obtainable;

c. specification of the means to collect MOM;

d. assurance of the validity and reliability of measures for correct interpretation with quantifiable levels of confidence;

e. awareness that variation in measurements (e.g., due to human involvement) may cause unacceptable levels of uncertainty, hence the analyst must pay particular attention to measurements related to the human factor;

f. consideration that although MOFE may provide the most persuasive measures from the military perspective, MOE and MOP are the most meaningful from the OR analyst viewpoint; and

g. accountability for the principles of reliability and validity to avoid the risk of generating false conclusions.

Information Technology will continue to have major impacts on military organization and

operational concepts. New capabilities of command and control systems will effect the underlying C2 processes requiring further analysis to determine the appropriate measures of merit.

The domain of the analysis of the effectiveness of information technology on Command and Control remains difficult. The R&D community has made slow, but perceptible gains over the years; the complexity of C2 offers challenges for further advances.

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APPENDIX A DIVISION HQ PERFORMANCE EVALUATION

Division Command and Control

Performance Evaluation

Planning and Monitoring

Functional Elements HQ Cells

Commander

- G1 Personnel
- G2 Intelligence
- G3 Operations
- G4 Supply
- G5 Civil Military Cooperation

  - Manoeuvre
  - Fire Support
  - Engineers
  - Tactical Aviation
  - Offensive Air Support
  - Signals
  - Electronic Warfare

General Steps

Receive directions from higher headquarters

Develop concept of operations and planning guidance

Staff check of resources and identify options for courses of action

Develop outline plan

Develop detailed plan, staff estimates

Preparation and issue of orders

Execution of orders

Planning Phase

- Develop planning guidance
- Complete staff checks
    - G1 personnel
    - G2 intelligence
    - G3 operations
    - G4 supply
    - Artillery
    - Engineers
    - Signals
    - Electronic Warfare
    - Tactical Aviation
    - Offensive Air Support

- Produce outline plan

- Complete estimate:
- G1 personnel
    - replacements plan
    - medical plan
    - military police plan
- G2 intelligence
    - intelligence estimate
    - STAIR (surveillance, target acquisition, intelligence and reconnaissance) plan

    - Counter STAIR plan
    - prepare meteorological information
    - map acquisition and distribution plan
- G3 operations
    - develop courses of action
    - prepare tactical plan including tasks, priorities, allocations of resources, movement plan, and coordination measures
    - complete integration of branch plans into operation plan
- G4 supply
    - determine requirements, priorities, availabilities, shortfalls
    - supply estimates: personnel consumption, ammunition, POL
    - transport
    - maintenance
    - dumping program
    - completion of administrative plan
- Artillery
    - complete fire support plan
        - allocate fire support resources
        - defensive fire plan
    - prepare division nuclear sub-package
- Engineers
    - engineer support plan including task specifications, priorities, and resource allocations
    - mobility tasks plan
    - counter mobility tasks plan
    - survivability tasks plan
- Signals
    - plan headquarters location and move
    - command and signal plan
    - combat net radio plan

  - line plan
  - dispatch riders
  - trunk system plan
  - maintenance plan
- Electronic Warfare
  - electronic warfare counter measures plan
  - electronic warfare support plan
- Tactical Aviation
  - aviation support plan
  - attack helicopter mission plan(s)
  - utility helicopter mission plan(s)
- Offensive Air Support
  - offensive air support plan
  - pre-planned mission plan(s)

- Completion of orders
  - operation order
  - administrative order
  - intelligence order
  - fire support order
  - engineer order
  - signals order
  - electronic warfare order
  - aviation order

Information Exchange in Planning

Transactions by originator:

1. to seek approval or concurrence from the respondent; for example, G4 seeking approval from G3 for supply movement routes;

- to alter planning directions or guidance
- to perceived tasks, requirements or priorities
- for proposed locations, routes, schedules, etc.
- for operation order contribution - for cell's plan

2. to seek information from the respondent; for example, G3 seeking information on enemy situation from G2;

- to clarify directions or planning guidance
- on own tasks requirements or priorities
- on own situation, locations, strengths
- on availability of own resources - on respondent's situation, locations, strengths
- on availability of respondent's resources
- on content or status of respondent's plan

3. to supply (unsolicited) information to the respondent; for example, G2 providing an intelligence briefing to the engineer advisor.

- to clarify directions or planning guidance
- on own tasks, requirements or priorities - on own situation, locations, strengths
- on availability of own resources
- as part of regular briefing or report (e.g INTSUM)
- on content or status of own plan
- on event or situation of interest to respondent

Impact of transactions:

Result or impact for the originator/respondent

- no impact
- caused delay
- prevented delay or speeded up work
- caused unnecessary additional work
- prevented doing unnecessary work
- prevented making error in plan
- improved quality of plan

Importance of transactions

- critical
- useful
- could be critical
- could be useful
- not important
- unknown

Additional information to develop flows of information

- the originator's formation and cell
- the respondent's formation and cell
- the transaction medium
- the time when the transaction was originated and the time when it was completed
- delays or interruptions in transactions

Factors for evaluation of the quality of plans

1. lack of correspondence with commander's intentions;
2. tactically inappropriate deployment or manoeuvre of resources;
3. inappropriate definitions of tasks;
4. inappropriate priorities;
5. underestimated resource requirements;
6. improper allocation of resources to tasks;
7. underestimates of capacities of allocated resources to meet task requirements;
8. incorrect or unnecessarily complicated coordination requirements;
9. incorrect interpretation of intelligence estimates of enemy capabilities;
10. underestimates of difficulties posed by ground or terrain;
11. failure to account for contingencies;

(If a plan turns out to need changes or fails, the quality of plan assessments would make it possible to diagnose whether or not the changes were required because of shortcomings in planning support systems or because of shortcomings in the quality of the plan.)

Monitoring Phase

Objectives.

- maintain an accurate and current picture of the status of operations
- provide commanders the means to quickly adjust plans

Measures

- information transmitted in command post networks

  - volumes and times, averages and variations, ratios higher to lower headquarters
- comprehension of situation
  - disposition of subordinate units
  - nature of enemy activity
  - sources of vulnerability
  - orders currently in effect
- information exchange among cells
  - prevented delay or speeded up operations
  - caused unnecessary additional operations
  - provided critical information on respondent's situation
  - provided critical information on own situation
  - increased respondent's knowledge of respondent's situation

- execution of plan alterations
  - contributing factors
    - change in higher formation's plan
    - change in own formation's plan
    - change in lower formation's plan
    - change in another branch's plan requiring change in own plan
    - unanticipated losses of personnel or equipment
    - unanticipated shortfalls in resources
    - failure to meet operations order schedule
    - reaction to newly discovered enemy actions or manoeuvres
    - unanticipated ground or terrain obstacles

  - necessity for change due to:
    - the original plan inappropriate
    - occurrence of unanticipated events
    - multiple options designed to create or exploit opportunities

- time information includes:
  - time of event that created need to alter plan
  - time of decision to alter plan
  - time when work on altering plan started
  - time when plan alteration was completed
  - time when new order was issued

- effort required to produce the plan
  - repeat entire planning cycle
  - reworked requirements
  - redefined tasks or priorities
  - reworked resources quantities or allocations
  - reworked movements, locations, or timings
  - made minor adjustments

- impact on other operations:
  - alteration required changes in plans at subordinate formation
  - alteration required change in plans of one or more other branches
  - alteration required change in higher formation's plan

- expected outcome of plan alteration:
  - avoid failure to achieve main operation mission objectives
  - avoid failure to meet one or more of own mission objectives;
  - prevent unnecessary losses of personnel or equipment;
  - exploit unanticipated opportunity to achieve mission objectives sooner or more efficiently;
  - exploit unanticipated opportunity to inflict losses on enemy, or thwart enemy operations.

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